

Potencial of invasive acacia species as bioenergy producers

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Abstract: Most fast-growing forest tree species used for biomass-for-energy production in Europe may be inadequate for that objective under Mediterranean climate conditions, due to summer drought intensity. In Portugal, exotic woody species well adapted to summer water stress, such as *Eucalyptus globulus* (blue gum) and acacias, may be more promising for biomass production than woody natives. The use of invasive acacias as a bioenergy source may be matched with eradication programmes that are envisaged by the Portuguese regulation on invasive species. However, effects of summer drought on these plants must be clarified. The objective of our study was to assess the biomass production performance of blue gum and acacia species under controlled conditions, with and without summer irrigation. An experiment with *Eucalyptus globulus*, *Acacia melanoxylon*, *A. dealbata* and *A. pycnantha* was installed in the Bioenergetic Plant Facility (BioenergiSA) within the campus of the Instituto Superior de Agronomia (ISA) aiming to assess the biomass production after 1, 2, 3, 4 and 5 years, and 1 and 2 years after coppice. The plots were installed in the beginning of 2012, survival and growth were monitored along one year and biomass production was evaluated after one year by the harvest method. The results showed a very low survival in rainfed plots of eucalypt and in both irrigated and rainfed treatments of *Acacia dealbata*, whereas irrigated and rainfed *Acacia pycnantha* had similar survival rates. The best growth rates, evaluated by total tree height, were measured in irrigated eucalypt and *A. pycnantha*, which also had the highest biomass production on an area basis. The evolution of the experimental plots along the next few years and the sprouting vigour after harvest will be crucial for economic and environmental validation of the study hypothesis.

Keywords: Bioenergy, eradication, exotic species, Portugal, survival rate.

Resumo - Potencial das acácias invasoras para a produção de biomassa para energia: A maioria das espécies florestais de crescimento rápido usadas na Europa para produção de biomassa para energia pode ser de pouca utilidade em clima Mediterrâneo, com secura estival pronunciada. As espécies lenhosas exóticas bem adaptadas ao stress hídrico estival, como o eucalipto e as acácias, podem ser mais promissoras em Portugal. O uso das acácias como fonte de biomassa pode articular-se com a execução de planos de erradicação previstos na Lei, devido ao seu carácter invasor. No entanto, o efeito da secura estival no crescimento destas espécies deve ser clarificado. Os objectivos deste estudo consistem em determinar a produção de biomassa de eucalipto e acácias sob condições controladas, com e sem rega estival. Para o efeito, estabeleceu-se, no Campo Pedagógico de Plantas Bioenergéticas (BioenergiSA) do Instituto Superior de Agronomia (ISA), um ensaio com *Eucalyptus globulus*, *Acacia melanoxylon*, *A. dealbata* e *A. pycnantha*, para avaliar a produção de biomassa ao fim de 1, 2, 3, 4 e 5 anos, bem como em talhadas após 1 e 2 anos. O ensaio foi instalado no início de 2012 e a sobrevivência e o crescimento monitorizados ao longo de um ano, tendo-se avaliado a produção no final do ano. Os resultados obtidos demonstraram uma sobrevivência muito baixa no tratamento não regado de eucalipto e em ambos os tratamentos de *Acacia dealbata*, não se registando diferenças entre os tratamentos regado e não regado de *Acacia pycnantha*. Os melhores crescimentos, avaliados pela altura das árvores, foram em eucalipto e *A. pycnantha* regados. Estas espécies, que também apresentaram a maior biomassa por unidade de área, obtiveram valores claramente superiores nos tratamentos regados. A evolução das parcelas experimentais nos anos vindouros e o vigor da rebentação das touças após corte serão essenciais para a validação económica e ambiental das hipóteses formuladas neste estudo.

Palavras-chave: Bioenergia, erradicação, exóticas, Portugal, sobrevivência.

INTRODUCTION

Plant biomass is the single most important renewable energy source and a key choice to also contribute to fulfil the engagements of the Kyoto Protocol of reducing greenhouse gas emissions and to replace fossil fuels (FAAIJ, 2006). Given the existence of raw material in Portugal and the negative externalities (forest fires) of letting this raw material accumulate in forests, the National Forest Strategy (DGRF, 2006) proposes that priority should be given to create a market for forest fuels, which would promote the further utilisation of residual biomass and reduce net costs of stand clearance.

Most short rotation energy crops used in Europe (e. g. willows and poplars) may be of limited usefulness under Mediterranean summer drought conditions. Exotic trees well adapted to summer stress, such as eucalyptus and acacias, may be more promising as biomass producers in Portugal. The area of eucalypt plantations in Portugal significantly increased over the last decades (BORGES and BORGES, 2007; ICNF, 2013), but they may become sensitive to changes in the international pulp markets that compromise its use and economic value. A reasonable knowledge on biomass production and management options in eucalypt coppices is already available (FABIÃO, 1986; FABIÃO *et al.*, 1995; CARNEIRO *et al.*, 2008; CARNEIRO *et al.*, 2009) and may become a key factor on their conversion to bio-energy production.

Australian species of the genus *Acacia* are an environmental problem in several areas of Europe, especially in France, Spain and Portugal due to the invasive character of some of them (CAMPOS *et al.*, 2002; MARCHANTE *et al.*, 2008b; RICHARDSON and REJMÁNEK, 2011). Due to its colonizing capacity, wattles may threaten native habitats by competing with vegetation communities and smothering associated fauna, and thus reducing native biodiversity (HOFFMANN *et al.*, 2002). In Portugal, these species are not anymore allowed in plantations and the restrictive law recommends their control or eradication through large scale plans. As control actions involve high costs, mainly due to the necessity of several follow up control actions, the use of their biomass as raw material for energy and/or bio-products may be an alternative (SANTOS *et al.*, 2004; GRUPO DE TRABALHO DO MADRP DE ENERGIAS ALTERNATIVAS, 2005) to compensate the costs of eradication.

The aim of this study consists in the improvement of knowledge on the potential of woody species well adapted to Portuguese summer drought as energy crops under Mediterranean climate. Seedlings of *Eucalyptus globulus* clones with high biomass production were used as a reference. *Acacia melanoxylon*, *A. pycnantha* and *A. dealbata*, frequent invaders of abandoned fields and coastal sand dunes, were privileged as target invader species, based on literature referring their biomass production performance and, in the case of *A. melanoxylon*, owing to its ability for fast growth and high dimension at maturity (MEDHURST *et al.*, 2003). Aiming the establishment of a controlled experiment, these species were propagated in nursery from seeds collected in existing Portuguese stands. The objective was to clarify the feasibility of using young regeneration that usually follows the harvest of dominant *Acacia* trees as raw material for bio-energy, partially supporting the costs of eradication follow up in subsequent years.

METHODS AND MATERIALS

Plant materials

Seeds of *Acacia dealbata*, *A. pycnantha* and *A. melanoxylon* were collected in wild Portuguese stands, respectively from interior Central Portugal, Central Algarve, and Sintra Forest Perimeter. They were subjected to hot water (80-90°C) pre-treatment for 4 hours to break seed coat dormancy, before sowing in propagation liner trays in November 2010 at Instituto Superior de Agronomia (ISA) nursery. Seedlings of a *Eucalyptus globulus* clone, with high biomass production, were obtained from Altri Florestal. Before planting, a random sample of 16 seedlings of each species were characterized for height and biomass (aboveground and roots).

Experimental design

The field trials were established in the biomass-for-energy facility (BioenergISA) at ISA. Seedlings were installed in January 2012 and the selected species were established with two treatments: near-optimal drop irrigation (from 14 June to 29 October, totalising ca. 1200 L m⁻²) and a rain fed control. To avoid effects of water percolation in the soil, the rain fed and irrigated plots were separated and the former installed at higher elevation than the latter. The location of species in treatments was randomized. The near-optimal irrigation was set regarding the evapotranspiration values daily published online by the Portuguese Weather Survey Authority (available at http://www.ipma.pt/pt/agrometeorologia/mapas/diario/index.jsp?page=deto_co.xml).

Each species and treatment occupies an area of 6×5 m². Seedlings were planted at a compass of 0.5×0.5 m², *i.e.*, with a density of 4 m⁻². One year after planting, ca. 1/3 of installed plants (adjusted according to survival) of each species and treatment was randomly sampled for above ground biomass assessment.

Measurements and sampling

Tree height (h) of measurable living seedlings in each plot was assessed with a measuring tape at planting and 7, 41, 70, 129, 160, 257 and 350 days after planting and survival rate evaluated.

Biomass production was evaluated by the harvest method, collecting at least 30 seedlings of each species and treatment. Each plant was divided into three components namely stem, twigs and branches, and leaves; they were weighed to the nearest 0.001 g and values compiled for total fresh weight biomass; they were then oven-dried at 80°C until constant weight (at least 48 hours) and weighted to obtain oven-dry biomass. Aboveground dry weight per hectare for each species was also estimated, accounting for mean tree dry weight and survival in each treatment.

Data handling and statistical analysis

Differences in mean tree height and mean aboveground total and component biomass across species and treatments were tested through Analysis of Variance (two-way ANOVA; factors: species * treatments). Post-hoc analyses were conducted using the Tukey test for multiple comparisons of means. All tests were done using the statistics software package IBM SPSS Statistics 19.0.0 (IBM

Corporation, Somers, NY, USA), considering a significance level of 5% ($\alpha=0.05$). Normality of data distribution and homogeneity of variance were confirmed by Kolmogorov–Smirnov test and Levene test, respectively.

RESULTS

Seedling characterization

The mean height, dry weight and root to shoot biomass ratio of eucalypt and acacia seedlings are shown in Table 1. Eucalypt seedlings were smaller than those of the three acacia species and showed lower root/shoot biomass ratio than those of acacias, probably due to vegetative origin of plants. The three acacia species ranked in aboveground height *A. pycnantha* > *A. melanoxylon* > *A. dealbata*, whereas *A. dealbata* and *A. melanoxylon* changed positions when mean total biomass was considered. However, *Acacia melanoxylon* had higher root/shoot ratio than the other species included in this study.

Table 1. Seedling characteristics of *Acacia dealbata*, *A. melanoxylon*, *A. pycnantha* and *Eucalyptus globulus* before planting in treatment plots.

Species	Mean height (cm)	Oven dry weight (g)			Root/Shoot ratio
		aboveground	belowground	total	
<i>Acacia dealbata</i>	22.0 ± 1.2	0.65 ± 0.08	0.47 ± 0.07	1.12 ± 0.15	0.70 ± 0.04
<i>Acacia melanoxylon</i>	26.6 ± 1.8	0.43 ± 0.04	0.60 ± 0.05	1.03 ± 0.08	1.42 ± 0.09
<i>Acacia pycnantha</i>	30.6 ± 1.9	2.48 ± 0.28	1.98 ± 0.23	4.46 ± 0.45	0.85 ± 0.07
<i>Eucalyptus globulus</i>	21.8 ± 0.5	1.42 ± 0.07	0.44 ± 0.02	1.87 ± 0.09	0.31 ± 0.01

Seedling survival

Survival rates of the species used in the present study are shown in Table 2. The results revealed a very low survival in rain fed plots of eucalypt (25%) and in both irrigated and rain fed treatments of *Acacia dealbata* (30 and 49.2 %, respectively). *A. pycnantha* had the highest proportion of survival in both areas, irrigated and rain fed (respectively 94.2 and 93.3%), followed by irrigated eucalypt (90%) and *A. melanoxylon* (72.5%).

Tree growth

Tree growth along the first year after planting was evaluated by mean tree height (Figure 1). Rain fed eucalypts were all harvested previously to the last measurement in irrigated treatment plot and final growth comparison and statistical analysis were performed between trees slightly different in age, but Figure 1 shows that growth of irrigated plants along that short time interval was negligible.

The highest growth performances were observed in irrigated eucalypt and *A. pycnantha*, attaining 100.6 and 109.9 cm, respectively. These species also had greater heights in rain fed plots (77.9 and 73.6 cm) than all the other *Acacia* species, in both irrigated and rain fed treatment plots.

In all species except *A. dealbata* irrigation significantly ($p<0.05$) contributed to higher growth than that

observed in rain fed treatment plots. *A. dealbata* which had a higher growth in rain fed than in irrigated plot (29.1 cm vs. 25.7 cm), but the difference was not statistically significant.

Table 2. Survival (% of initial seedling quantities) of *Acacia dealbata*, *A. melanoxylon*, *A. pycnantha* and *Eucalyptus globulus* in treatment plots along the first year of the experiment.

Species	Treatments	Days after planting						
		7	41	70	129	160	257	350
<i>A. dealbata</i>	Irrigated	100.0	75.8	69.2	63.3	51.7	34.2	30.0
	Rain fed	100.0	91.7	90.0	86.7	76.7	53.3	49.2
<i>A. melanoxylon</i>	Irrigated	100.0	100.0	99.2	99.2	86.7	80.8	72.5
	Rain fed	100.0	100.0	100.0	94.2	89.2	60.0	59.2
<i>A. pycnantha</i>	Irrigated	100.0	100.0	99.2	97.5	95.8	94.2	94.2
	Rain fed	100.0	98.3	95.0	95.0	95.0	94.2	93.3
<i>E. globulus</i>	Irrigated	100.0	97.5	97.5	95.0	90.8	90.8	90.0
	Rain fed	99.2	96.7	96.7	95.8	90.8	27.5	25.0

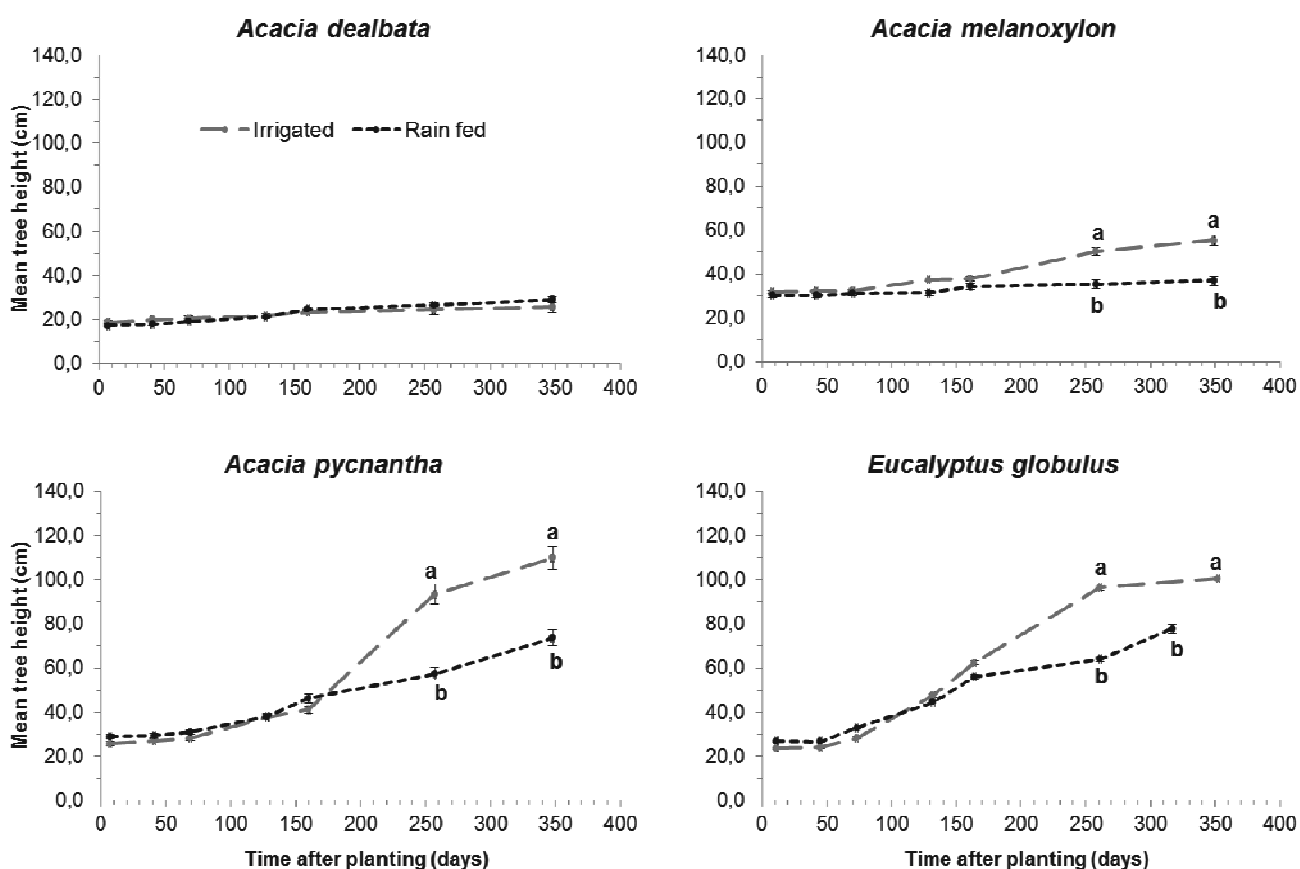


Figure 1. Tree height (cm) increase for *Acacia dealbata*, *A. melanoxylon*, *A. pycnantha*, and *Eucalyptus globulus* through the first year after planting (vertical bars represent ± 1 standard error).

Different characters indicate statistically significant differences between treatments in the same measuring date ($p < 0.05$, ANOVA procedure). Rain fed eucalypts were all harvested previously to the

last measurement in irrigated treatment plot (see text).

Biomass production

Table 3 shows the average values of total and component tree aboveground dry biomass in the studied acacia species and eucalypt one year after planting. *Acacia pycnantha* trees in irrigated plots showed the potential to accumulate more biomass than all the other species, irrespective of treatment ($p < 0.05$), attaining 46.3, 13.0, 39.8 and 99.1 g dry biomass tree⁻¹ respectively for stem, branches, leaves, and total aboveground.

Total aboveground dry biomass of *A. pycnantha* was estimated in an area basis at about 3732.5 and 515.9 kg ha⁻¹ respectively in irrigated and rain fed plots, whereas irrigated *Eucalyptus globulus* only attained 1039.3 kg ha⁻¹ (and 290.9 kg ha⁻¹ in rain fed treatment plot). *A. dealbata* ranked the lowest values in both treatments (8.7 and 37.9 kg ha⁻¹ in irrigated and rain fed respectively), followed by *A. melanoxylon* with 52.2 kg ha⁻¹ in rain fed treatment.

Table 3. Mean aboveground dry biomass for the whole-tree and its components (g tree⁻¹) of *Acacia dealbata*, *A. melanoxylon*, *A. pycnantha* and *Eucalyptus globulus* and their total estimated aboveground biomass (kg ha⁻¹) in treatment plots 1 year after planting. Values in the same column followed by different characters differ significantly ($p < 0.05$, ANOVA procedure and Tukey test).

Species	Treatments	Biomass production (g tree ⁻¹)				Estimated production by area (kg ha ⁻¹)
		Stem	Branches	Leaves	Whole tree	
<i>Acacia dealbata</i>	Irrigated	0.507 a	0.053 a	0.185 a	0.745 a	8.7
	Rain fed	0.783 ab	0.117 ab	1.027 a	1.927 ab	37.9
<i>Acacia melanoxylon</i>	Irrigated	6.217 a	0.828 a	5.009 ad	12.053 a	349.5
	Rain fed	0.893 ab	0.110 ab	1.205 a	2.208 ab	52.2
<i>Acacia pycnantha</i>	Irrigated	46.331 c	12.978 c	39.783 c	99.092 c	3732.5
	Rain fed	5.487 ab	1.320 ab	7.012 ab	13.818 ab	515.9
<i>Eucalyptus globulus</i>	Irrigated	9.461 a	1.640 a	16.987 bd	28.089 a	1039.3
	Rain fed	7.480 ab	2.284 ab	19.326 b	29.090 ab	290.9

Allocation of dry biomass into different components as a percentage of the total aboveground dry biomass for each species is illustrated in Figure 2. Dry biomass of stem of most acacia species accounted for about 40-60% of the total above-ground dry biomass, while in *Eucalyptus globulus* did not exceed 33.7% in irrigated plots. Nevertheless, leaf allocation in eucalypt was higher (60.5% for irrigated and 66.4% for rain fed) than in acacia species, where it ranged between 25% (irrigated *A.*

dealbata) and 55% (rain fed *A. melanoxylon*). Branches generally had the lowest dry biomass allocation, with a maximum value for irrigated plots of *A. pycnantha* with 13.1% of the total above-ground biomass.

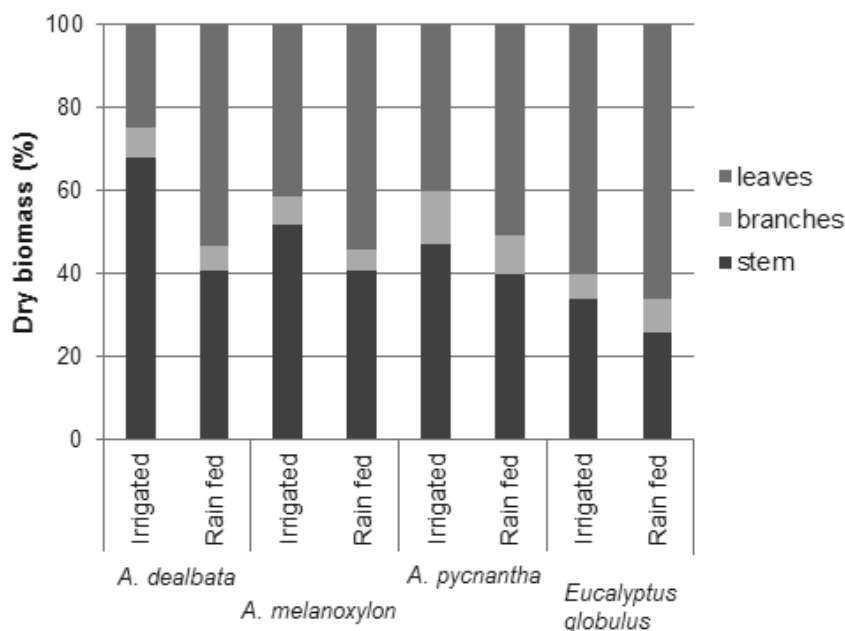


Figure 2. Allocation of dry biomass into different components as a percentage of the total aboveground dry biomass for *Acacia dealbata*, *A. melanoxylon*, *A. pycnantha* and *Eucalyptus globulus*.

DISCUSSION

The most surprising result obtained within the present study was the low survival, growth and aboveground biomass production of planted *Acacia dealbata*, especially under irrigation, which has been pointed out as one of the most aggressive and invasive species in terrestrial ecosystems in Portugal, well adapted to margins of water courses (MARCHANTE *et al.*, 2005; FERREIRA *et al.*, 2011; GIBSON *et al.*, 2011). Our results suggest that its invasiveness may be at least partially related to ability to sprout from roots and stumps, although this species tend to increase its invasive character after fire and/or soil disturbance, and also in relation to long-term soil-stored seed banks (MARCHANTE *et al.*, 2008a; LORENZO *et al.*, 2010; GIBSON *et al.*, 2011). Nevertheless, debility of seedlings produced within the experiment was observed at nursery and confirmed in the general characterization of plants before planting. Ongoing studies in seedling propagation have already suggested that such debility is not related to the seed origin, since it was confirmed with different seed provenances after the conclusion of this study. Mutualistic relationships with nitrogen-fixing bacteria were not considered in our study and may also contribute to the low establishment success of this species (GIBSON *et al.*, 2011).

An opposite trend was observed in *Acacia pycnantha*, which confirmed an appreciable potential for

early biomass increase even in rain fed conditions. One of our main objectives was to confirm the early biomass production potential of invasive acacias in order to economically support eradication follow up, as discussed by KULL *et al.* (2011), through the harvest of young plants to be used as raw material for energy production. Biomass production in this acacia one year after planting was 1.8-3.4 times higher than that of *E. globulus*, a reference in similar environmental conditions, depending on applied treatment (respectively rain fed and irrigated). This species was widely used to cover areas of shallow and dry soils under management of the Forest Authority in Algarve, where nowadays it occupies a significant area. It was used in the past for fuel wood, but this type of utilization strongly decreased over the last decades and almost disappeared in that region, allowing good perspectives for bio-energy purposes.

Our results were inconclusive for *A. melanoxyton*, which still requires further research to confirm its potential for early biomass production, crucial to at least partially support harvesting for energy in the early growth stage. In our study its biomass production was low, especially under rain fed conditions. MEDHURST *et al.* (2003) pointed out its tolerance to shadow and competition in early growth stages and the value of that tolerance to improve tree form. Nevertheless, survival of *A. melanoxyton* in our study was only regular and tree height increase over the first year was poor, especially under rain fed conditions. As referred above for *A. dealbata*, occurrence of root nitrogen-fixing bacteria was not surveyed within this study and may influence the establishment success. It remains unclear whether vegetative propagation may explain, or not, invasiveness of this species in the wild.

Further research on this area should include acacia seedlings obtained by vegetative propagation, which may be better adapted to early fast growth than those obtained from seed, at least in *A. dealbata*, and survey of nitrogen-fixing bacteria nodules in seedling roots. This may be especially important to better understand early growth and invasiveness of *A. dealbata* that had a low survival and biomass production performance in our study. The inclusion of *A. longifolia* in this experiment is also envisaged by the authors, due to its importance as an invader of coastal areas in Portugal with strong impact on native plant communities (HELLMANN *et al.*, 2011).

CONCLUSIONS

A. pycnantha had an early biomass production clearly higher than that of *E. globulus* (the reference species in biomass production), allowing the conclusion that harvest for biomass may at least partially support the costs of follow up of seedlings emerging after eradication of larger trees.

This may also allow some speculation on the use and conversion of stands of this species that occur in areas of shallow and dry soils in southern Portugal, namely in Algarve, aiming energy production from their biomass.

Further research is still needed to confirm the feasibility of early harvesting of *A. dealbata* and *A. melanoxyton* for bioenergy, as well as to clarify the mechanisms of invasiveness in these species.

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